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ASSIGNMENT OF GLOBAL INFORMATION SYSTEM COORDINATES TO CLASSICAL MUSEUM LOCALITIES FOR RELATIONAL DATABASE ANALYSES

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Many decisions are made based on information concerning the flora and fauna of the world. With the development of a large number of technological breakthroughs such as computers, DNA sequencers, satellite imagery, image analyzers, etc., the volume of knowledge available concerning plants and animals is rapidly expanding and has grown beyond our ability to examine each study and data set in classical, "hands on" analyses. To more effectively share and interrogate data sets, a new field of science has evolved called Biological Informatics. (The current trend is to apply the term "Biological Informatics" to research involving Geographic Information Systems (GIS), systematics, ecology, etc. and to restrict "Bioinformatics" to research relating to genomics and molecular issues.) At the heart of Biological Informatics is the ability to use computers to examine massive data files in a critical synthesis. These syntheses utilize relational databases to examine geographical and temporal relationships in comparison to other data sets.

The Museum of Texas Tech University has been archiving biological specimens as a source of information on biocomplexity, disease, pollution, affects of agriculture, etc. for over thirty years. The Natural Science Research Lab's (NSRL) current collection was constructed to meet the needs of scientists and biologists, and to increase the potential of the collection through the use of ongoing technological development of computer software and hardware (Baker et al., 1997; Baker et al., 1998; Parker, et al., 1998). These collections of biological voucher specimens represent a valuable resource of information that may be explored in a relational format.

Beginning in 1996, a new relational database management system (WildCat) was designed and implemented to perform operations that traditionally were done by hand and to increase the potential of the electronic database (Monk, 1997; 1998). Specimen data archived in electronic databases such as WildCat normally are not used for computer analysis; the database is simply an archive. However, in order to be useful to a Geographic Information System (GIS), locality data must be in a different format than traditionally has been recorded and stored in collection databases. For example, a location such as *10 MI S LUBBOCK* cannot be analyzed by a GIS without operator assistance and extra computer time. Two types of locality data, Universal Transverse Mercator UTM coordinates and longitude and latitude, can easily be utilized by GIS software.

UTM coordinates are numerical data that depict exact geographical locations on a flat representation of the earth. A world map is divided into 60 zones of 6° each. To assign UTM coordinates for a specific location, the position within a zone is established. For instance, the state of Texas is situated in zones 13, 14 and 15 (see Fig. 1). UTM coordinates are expressed in meters, so the accuracy of a geographical location can be no greater than one meter. (Note: it is not the purpose of this paper to describe the UTM system. More information on the system can be found at http://www.maptools.com/UsingUTM/index.html.)

Generally, specimens collected and archived at the NSRL prior to 1990 were assigned only descriptive geographical locations that were not GIS compatible. The purpose of this project was to convert geographical locations of the mammals of Texas such as *1 MI N, 10 MI E LUBBOCK, 5 MI E ODESSA,* or *DALLAS* to UTM coordinates. The ultimate goal is to have UTM coordinates for all voucher specimens of mammals in the NSRL as well as for other mammal specimens collected in Texas that are housed in other collections in the United States (see Davis and Schmidly, 1994) so these collections can be interrogated using compatible, relational databases.

Several problems are encountered when assigning UTM coordinates to classical museum localities. First, not all localities recorded on tags of specimens contain equal accuracy, so it was necessary to document the level of accuracy for each locality. The precision index (McLaren et al., 1996) identifies the accuracy of UTM coordinates (see Appendix). For example, precision index 1.1 represents coordinates that had been obtained firsthand by the collector using Global Position System (GPS) technology. If the UTM coordinates were generated by computer from relative distance data, a precision index value of 3.0 was assigned. If a record had only the name of a county, the precision index value assigned was 4.0, indicating an accuracy of about thirty miles. Accuracy was a major consideration as it was not always possible to identify the exact location described on the specimen tag. For example, using the record *1 MI N, 10 MI E LUBBOCK*, it was impossible to identify the exact point in Lubbock from which the collector had orientation. Location records that contain only a county or have directions from parks, creeks, or other "non-distinct" features were assigned a precision index value of 4.0.

A second problem was that there were instances when the location (reference point) described on the tag was not identifiable on a current map (*5 MI FROM SALDINE*, for example). Such records could not be assigned UTM coordinates.

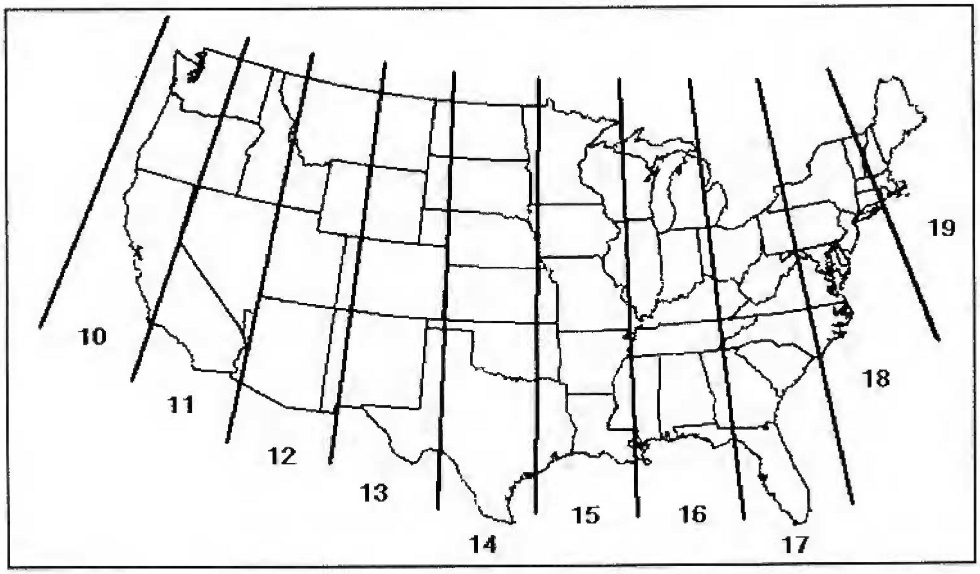


Figure 1. Map of the United States with UTM zones indicated (created by Peter H. Dana, University of Texas at Austin).

METHODS AND MATERIALS

Microsoft® Visual FoxPro™ version 5.0 was used to assign UTM coordinates to locality records in the NSRL's existing electronic database. A "dictionary" file containing the UTM coordinates of the cities and towns of Texas was obtained from the internet for use in this project. One characteristic of UTM mapping is that coordinates occuring in different zones must be converted or expressed relative to a single zone to allow them to be visualized on one map. In order to address this issue, the coordinates from the original data dictionary were converted to a single zone (14) regardless of their actual zone of occurrence. The digitizing system of ArcView® Geographic Information System (GIS) was used to accomplish this task. The coordinates of the cities and towns in Texas located in zones 13 and 15 were converted to zone 14.

The next stage of the project was to design software to analyze descriptive, geographical locations and assign UTM coordinates using the dictionary mentioned above. This software, identified as *UTM Converter,* deals with any number of records and can analyze the types of records commonly found in museum data files. The working time of the software depends directly on the number of records in the tables (original data file and data dictionary). The main operations of *UTM Converter* were run in a step-wise fashion. The software was designed to proceed step-by-step because it was useful after several of the operations to examine the data and identify records for which a mappable point could not be identified by the computer. These records could be flagged for later consideration while the remaining records would be used in subsequent steps of *UTM Converter.*

UTM Converter has nine options as follows:

1. Select Table
2. Select Dictionary
3. Add Columns
4. Separate Table
5. Browse Table
6. Assign UTM
7. Report
8. Drop Columns
9. Exit

In the **Select Table** and **Select Dictionary** options, the user specifies the name of the table that contains the records to be converted and the appropriate dictionary. To analyze the table, it should contain five additional fields: distance 1 (*dis1*), direction 1 (*dir1*), distance 2 (*dis2*), direction 2 (*dir2*), and city. The **Add Columns** option is used to add these fields to the table. The next step of the program is to separate (parse) the locality field into five distinct parts: distance 1, distance 2, direction 1, direction 2, and city. For example, records

1. *7.5 MI NW NOTREES*
2. *1.0 MI N, 9.0 MI W WELLINGTON*

will be parsed by the **Separate Table** option as is shown in table 1.

Many records have other descriptive information in the locality field. For example, a locality

Table 1. Separation of records.

dis1	*dir1*	*dis2*	*dir2*	*city*
7.5	NW			NOTREES
1.01	N	9.0	W	WELLINGTON

such as *1.0 MI N, 9.0 MI W WELLINGTON, NEAR CARBON BLACK ROAD* is not compatible with the *UTM Converter* program. It is essential to look through the table and remove such comments as *NEAR CARBON BLACK ROAD* to prepare the records for assignment of UTM coordinates (table 2). The **Browse Table** option was designed for direct viewing and editing of the data in the table.

The **Assign UTM** option of the program is used to assign UTM coordinates. The actual process involves (1) locating the city (and associated UTM coordinates) in the data dictionary, (2) converting the distances recorded in the distance 1 and distance 2 fields to meters, and (3) adding or subtracting these values from the city's coordinates. The **Assign UTM** option also assigns a precision index value of 3.0 to any coordinates calculated in this step.

The **Report** option was created to check the number of records to which UTM coordinates were successfully assigned. Once coordinates have been assigned, the **Drop Columns** option is used to delete those fields that were used only by this program and are not necessary for the database. These fields include direction 1 (dir1), distance 1 (*dis1*), direction 2 (*dir2*), distance (*dis2*), and city.

UTM Converter is available at no cost at http://nsrlmap.musm.ttu.edu/utm/project.htm. There is also a collection of data dictionaries for the United States available at the same location.

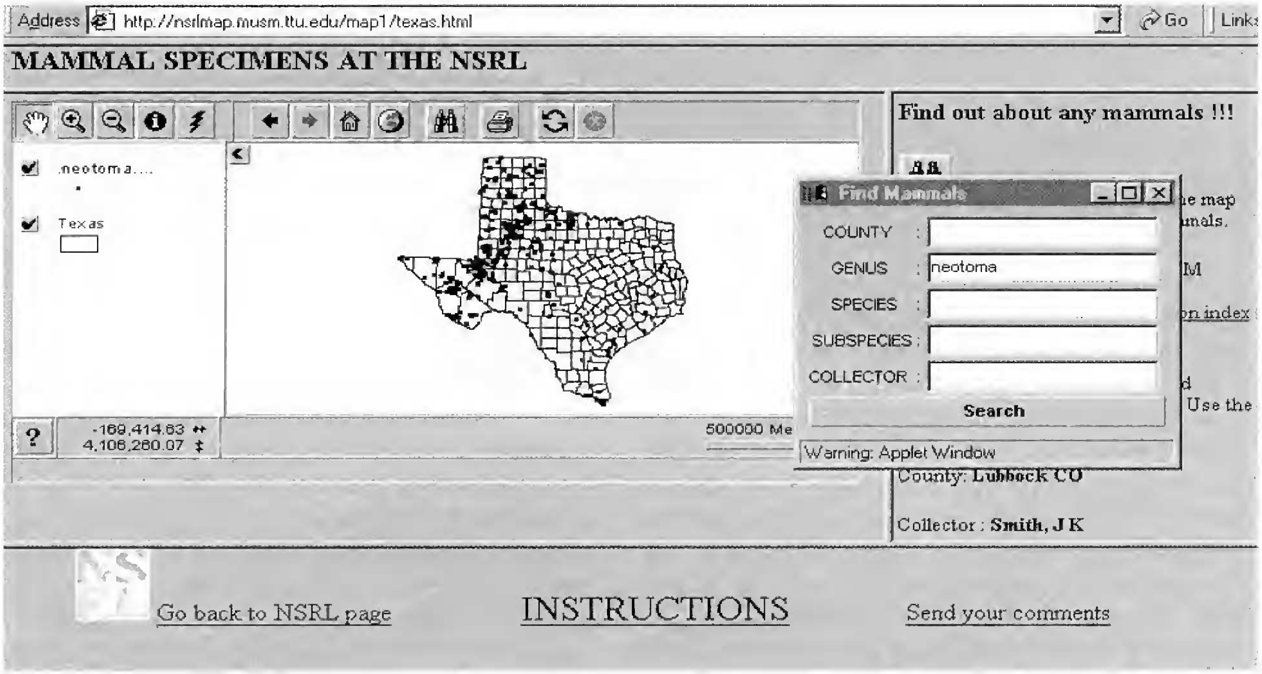
Table 2. Examples of records with UTM coordinates assigned.

dig1	*dir1*	*dig2*	*dir2*	*city*	*easting*	*northing*
7.5	NW			NOTREES	136362	3546991
1.01	N	9.0	W	WELLINGTON	374393	3859381

RESULTS

UTM coordinates were assigned to 15,220 locality records of mammal voucher specimens collected in Texas and archived at the NSRL. UTM coordinates were successfully assigned to 96.2% of the records, where 86% of the records were assigned by the software and 10.2% of the records were assigned manually. Moreover, UTM dictionaries were created for all fifty states in the USA and Puerto Rico using the appropriate zones in each state. The original data from which the dictionaries were created was from the US Census Bureau data found at http://ftp.census.gov.

Using *UTM Converter* and individual data dictionaries (see http://nsrlmap.musm.ttu.edu/utm/project.htm), it is possible for other institutions to assign UTM coordinates to localities for specimens from the United States. Geographical representation of the records assigned in this project (Mammals of Texas at the NSRL) is available at http://nsrlmap.musm.ttu.edu/map1/texas.html. The records to which UTM coordinates have been assigned are easily analyzed by GIS software. For example, the maps shown in the following discussion were developed using ArcView® GIS 3.1. This is an example of a Java™ client interaction with a server being used to produce dynamic, on-the-fly maps (see Fig. 2).



Address http://nsrlmap.musm.ttu.edu/map1/texas.html

MAMMAL SPECIMENS AT THE NSRL

Find out about any mammals !!!

COUNTY :
GENUS : neotoma
SPECIES :
SUBSPECIES :
COLLECTOR :

-169,414.63
4,106,280.07

County: Lubbock CO

Collector : Smith, J K

Go back to NSRL page

INSTRUCTIONS

Send your comments

Figure 2. Interactive MapCafé™ applet that produces dynamic maps, from data in a searchable, on-line database.

Discussion

UTM Converter assigned coordinates to 86% of the 15,220 locality records processed. After several stages of assigning records, it was necessary to correct spelling mistakes of localities, add some cities to the dictionary, and edit comments in the locality field of the main table. Following is an example of some localities to which UTM coordinates were assigned by *UTM Converter*:

1. 0.5 MI N, 0.5 MI W WHITEFACE
2. 1 MI SW GANADO
3. 1.5 MI W PLAINVIEW ON DONALD LEE TURRELL FARM
4. 2.25 MI N, 7.5 MI E QUANAH
5. 1 MI N, 1.5 MI W LUBBOCK

An additional, 10.2% of the records were assigned manually. These records contained data in a non-traditional format that could be located on a map, but could not be processed electronically. These locations were located on maps and UTM coordinates were then calculated manually. Examples of these follow:

1. 4 MI S, 7 MI E JCT 84 AND LOOP 289
2. 3.1 MI E JCT TEX 59 AND FR 1758 ON 1758
3. GUADALUPE MTS NATL PARK, UPPER DOG CANYON, RANGER STA.

Finally, 3.8% of the records could not be assigned UTM coordinates because the localities could not be identified on the map. The locality description did not contain enough information to accurately locate them. The following are examples of localities that could not be assigned UTM coordinates:

1. 3 MI S OF I 40, CARBON BLACK ROAD
2. 5 MI FROM SALDINE
3. 3 MI ? ODESSA
4. 1 MI E, 1 MI S THE CITY DUMP
5. DOUBLE U RANCH

The accuracy of records varied tremendously as is shown by the following examples:

1. *4TH AND QUAKER AVE, LUBBOCK*
2. *HOUSTON AREA*
3. *1.25 MI N, 3 MI W WINK*
4. *LUBBOCK CO.*

In the previous list, the first record is more accurate than the other records, hence more exact coordinates could be assigned to this location. The third record is second in order of accuracy. It is not known from what point in the city of Wink the collector traveled north and west, but since Wink is a small town, the possibilities are more limited. Lubbock Co. is large (about 30 by 30 mi), so an accurate location cannot be assigned. It is reasonable to assume, however, that the specimen was collected within the 30 by 30 mile area. The locality "*HOUSTON AREA*" is even more difficult, because it is impossible to determine if the locality is in the city of Houston, in the surrounding suburbs, or even in the general vicinity of Houston. The accuracy of each locality was documented using a precision index (see Appendix):

1. *4TH AND QUAKER AVE, LUBBOCK* (precision index 3.0)
2. *HOUSTON AREA* (precision index 5.0)
3. *1.25 MI N, 3 MI W WINK* (precision index 3.0)
4. *LUBBOCK CO* (precision index 4.0)

After assigning UTM coordinates, it was possible to use GIS software to better interrogate the database in an effort to understand mammal zoogeography and to answer other questions. Application of the GIS to this project included production of maps showing UTM locations of sites where field biologists collected and archived mammal specimens. The database may be queried by date, collector, genus, species, etc. Following are some examples of ways the distribution of voucher specimens of Texas mammals can be studied.

Voucher specimens housed in the NSRL have been collected throughout the state but most intensively in West Texas (Fig. 3). Collections from other museums (named in table 3) excluding the NSRL have been made throughout the state but are most intensive in North Texas where Dr. Fred Stangl and his colleagues' research efforts are well documented (Fig. 4). When these two data sets were combined (Fig. 5), it is apparent that most areas of the state have been sampled, albeit some more extensively than others. The mammal collection at Texas A&M University is the only major collection not represented in these data.

Once placed in a GIS, the distributions of taxa such as *Dipodomys ordii* (Fig. 6a, b), *Dipodomys merriami* (Fig. 7a, b), *Felis* and *Lynx* (Fig. 8a, b), and *Neotoma micropus* (Fig. 9a, b) easily can be depicted.

In addition, the history of mammal specimen collection at Texas Tech University can be visualized by examining the localities of collecting efforts over time. Prior to 1959, Texas Tech did not have an active program in mammalogy (Figs.10, 11). In the sixties, Robert L. Packard developed a strong mammalogy program as indicated by the number of localities in figure 12. Dr. Packard had many graduate students, including David Schmidly and others. The collection was expanded in the 1960's as these students completed master's theses and doctoral dissertations. In 1967, Robert J. Baker joined the Texas Tech faculty; he and his students also contributed significantly to the collection during the 1970's (Fig. 13), the 1980's (Fig. 14), and the 1990's (Fig. 15). Other mammalo-

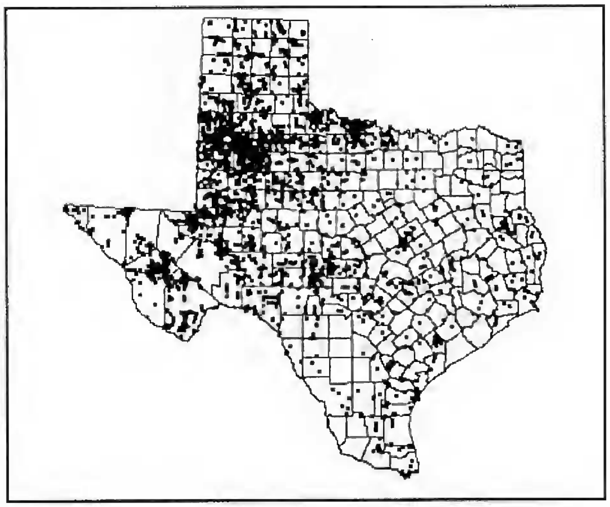


Figure 3. Distribution of all localities of mammal voucher specimens housed at the Natural Science Research Laboratory (up to 1998).

Table 3. Collections represented in David J. Schmidly's database of mammals collected in Texas (also known as the Condor database). Acronyms given are in accordance with The American Society of Mammalogists (ASM Acronym; Yates et al., 1987) and the Condor database (DB Acronym; Davis and Schmidly, 1994).

Collection	DB Acronym	ASM Acronym
American Museum of Natural History	AMNH	AMNH
Angelo State University, Vertebrate Research Collection	ASUVC	ASVRC
Big Bend Natural History Association, Big Bend National Park	BBNP	BBNHA
Baylor University, Strecker Museum	BUSM	SM
Corpus Christi State University Vertebrate Collection	CCSU	——
Carnegie Museum of Natural History	CMNH	CM
Dallas Museum of Natural History	DMNH	DMNH3
Field Museum of Natural History	FMNH	FMNH
Fort Worth Museum of Science and History	FWMSH	FWMSH
Los Angeles County Museum of Natural History	LACM	LACM
Louisiana State University Museum of Zoology	LSUMZ	LSUMZ
Museum of Southwestern Biology, University of New Mexico	MSBUN	MSB
Michigan State University	MSU	MSU
Museum of Vertebrate Zoology, University of California at Berkeley	MVZ	MVZ
Midwestern State Univ. Collection of Recent Mammals, Wichita Falls	MWU	MWSU
Philadelphia Academy of Science	PAS	ANSP
Stephen F. Austin University, Department of Biology, Nacogdoches	SFAZC	SFASU
Sul Ross State University, Vertebrate Collection, Alpine	SRSU	SRSU
Southwest Texas State	SWTS	——
Texas A&I University (now Texas A&M University at Kingsville)	TAIU	TAIU
Texas Natural History Collection, University of Texas at Austin	TNHC	UTLPA
Texas Wesleyan College, Museum of Zoology, Fort Worth	TWC	TWC
University of Illinois Museum of Natural History	UIMNH	UIMNH
University of Kansas Museum of Natural History	KU	KU
University of Michigan Museum of Zoology	UMMZ	UMMZ
University of Texas at Arlington Collection of Vertebrates	UTAVC	UTAVC
University of Texas at El Paso, Mammal Div., Lab. for Env. Biology	MALB	UTEP
U.S. National Museum	USNM	USNM
Witte Memorial Museum, San Antonio	WMSA	WMM

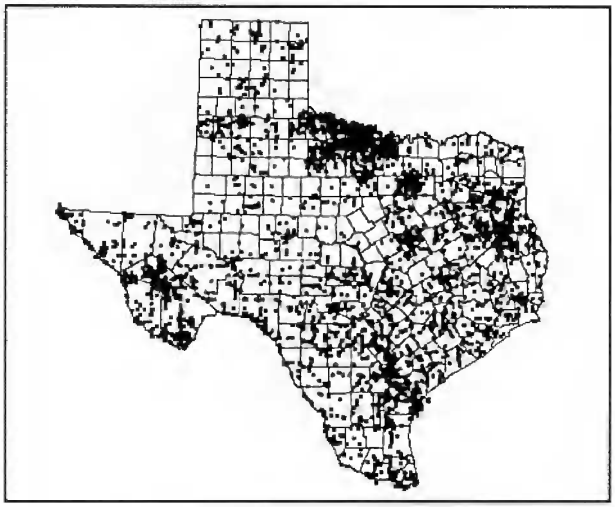


Figure 4. Distribution of all localities of mammal voucher specimens housed at other collections represented in Table 3 (up to 1991).

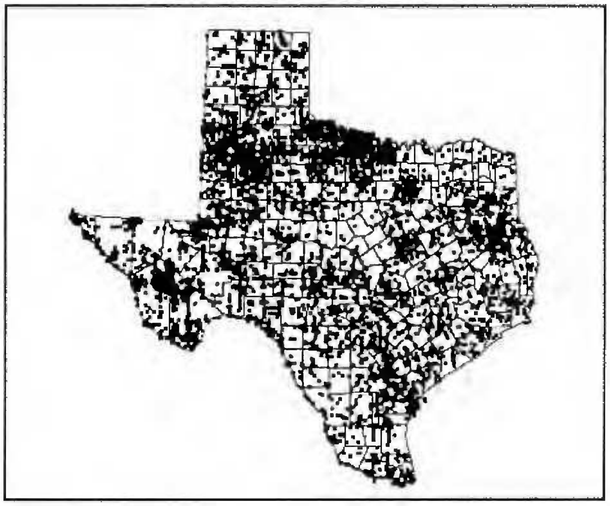


Figure 5. Localities of mammal specimens in all collections represented in Table 3 and the Natural Science Research Laboratory studied by David J. Schmidly for the Mammals of Texas (Davis and Schmidly, 1994).

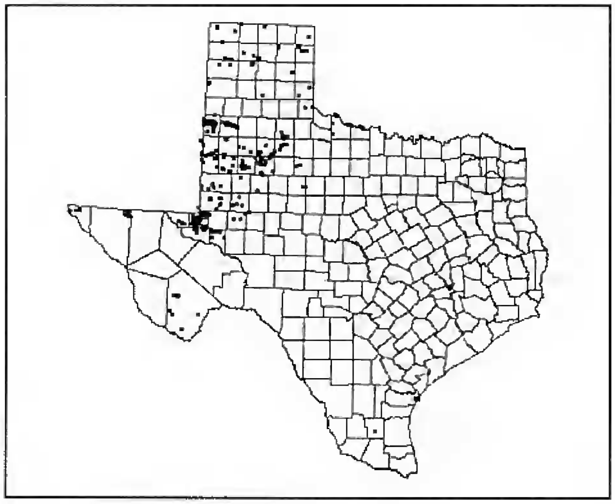


Figure 6a.

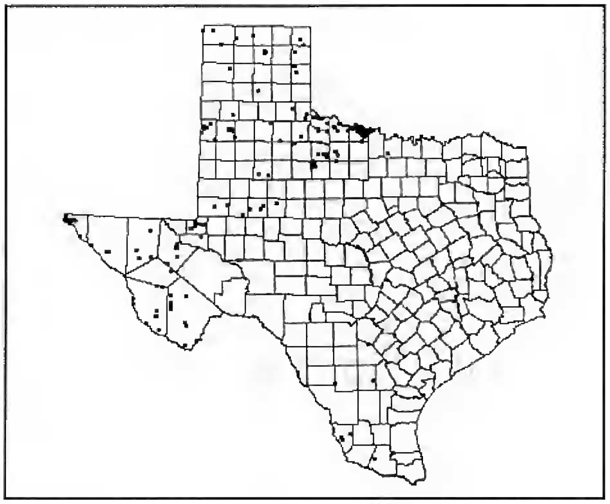


Figure 6b.

Distribution of localities where voucher specimens of *Dipodomys ordii* have been collected and stored (a) at the Natural Science Research Laboratory and (b) at other locations represented in Table 3.

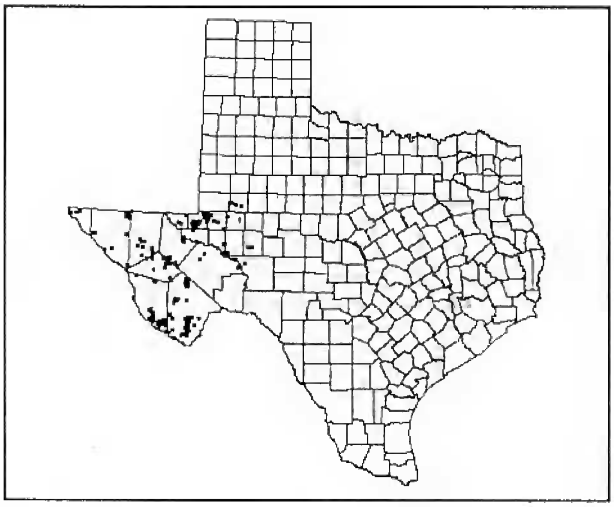


Figure 7a.

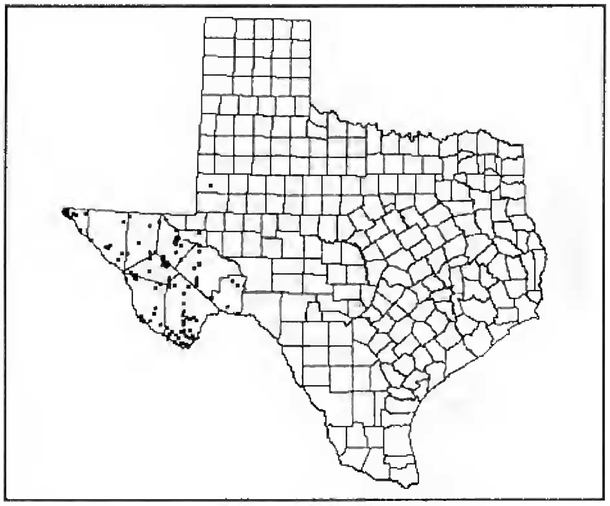


Figure 7b.

Distribution of localities where voucher specimens of *Dipodomys merriami* have been collected and stored (a) at the Natural Science Research Laboratory and (b) at other locations represented in Table 3.

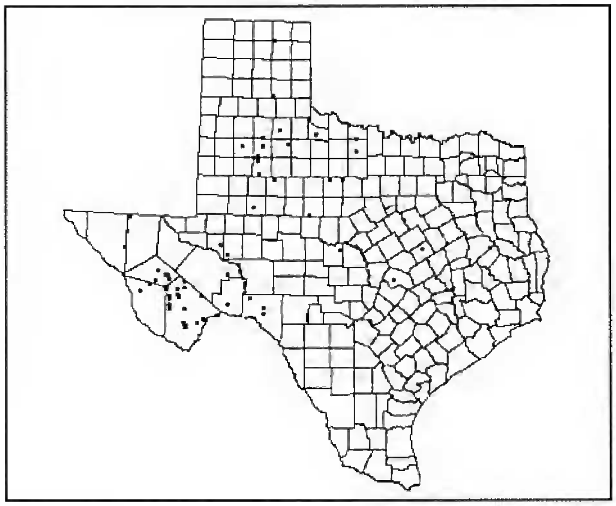


Figure 8a.

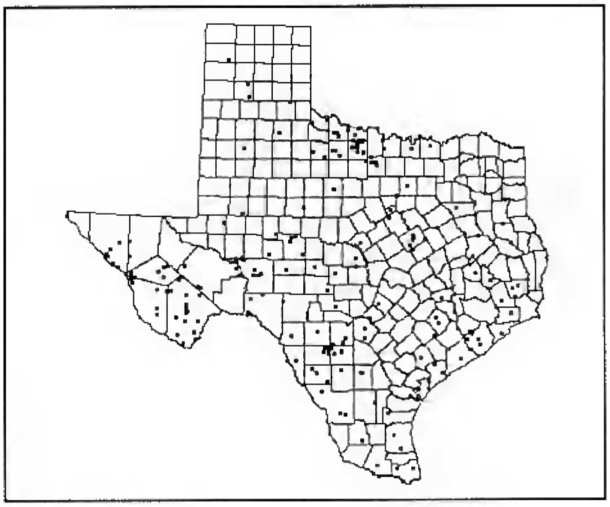


Figure 8b.

Distribution of localities where voucher specimens of *Felis* and *Lynx* have been collected and stored (a) at the Natural Science Research Laboratory and (b) at other location represented in Table 3.

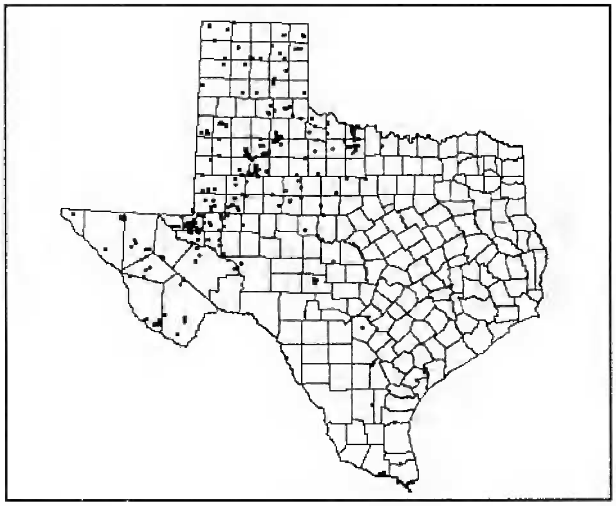


Figure 9a.

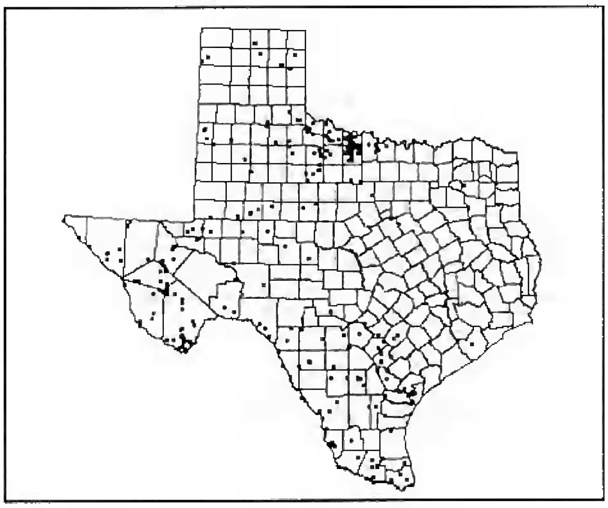


Figure 9b.

Distribution of localities where voucher specimens of *Neotoma micropus* have been collected and stored (a) at the Natural Science Research Laboratory and (b) at other locations represented in Table 3.

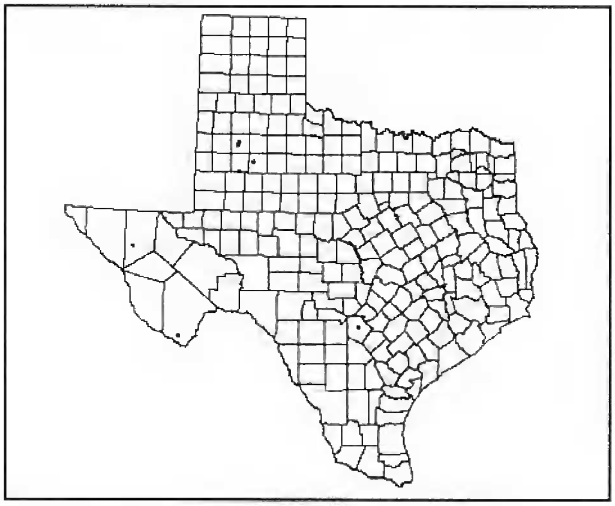


Figure 10. Localities of mammal specimens housed at the Natural Science Research Laboratory that were collected prior to 1950.

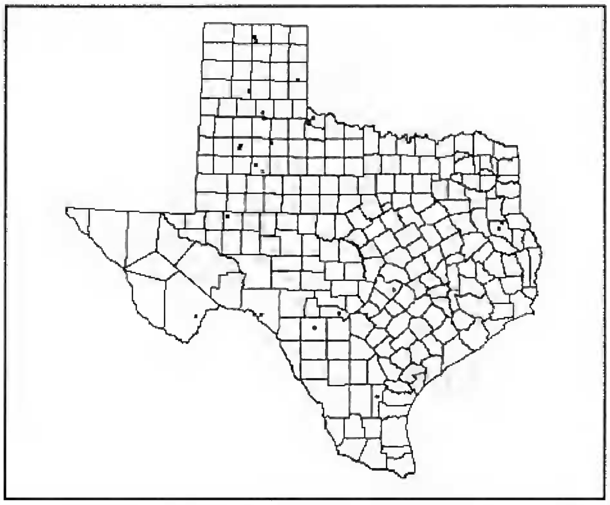


Figure 11. Localities of mammal specimens housed at the Natural Science Research Laboratory that were collected after 1 January 1950 and before 1 January 1960.

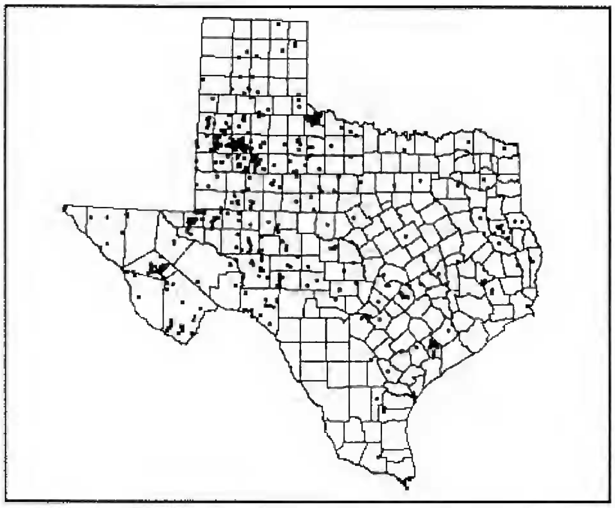


Figure 12. Localities of mammal specimens housed at the Natural Science Research Laboratory that were collected after 1 January 1960 and before 1 January 1970.

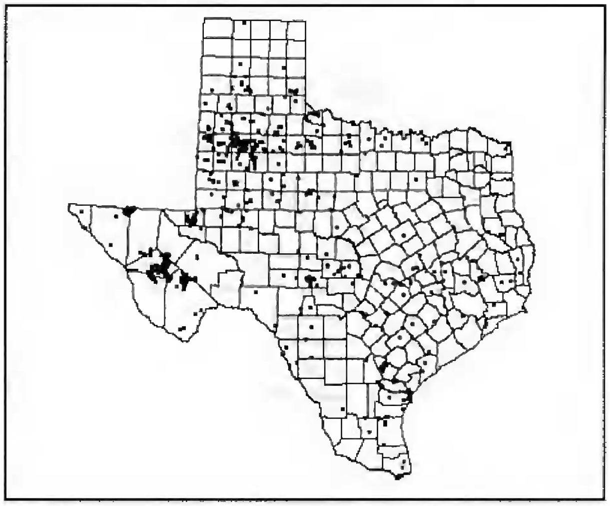


Figure 13. Localities of mammal specimens housed at the Natural Science Research Laboratory that were collected after 1 January 1970 and before 1 January 1980.

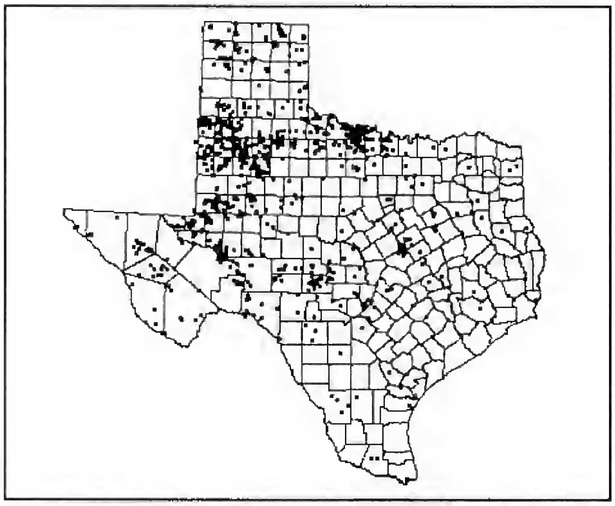


Figure 14. Localities of mammal specimens housed at the Natural Science Research Laboratory that were collected after 1 January 1980 and before 1 January 1990.

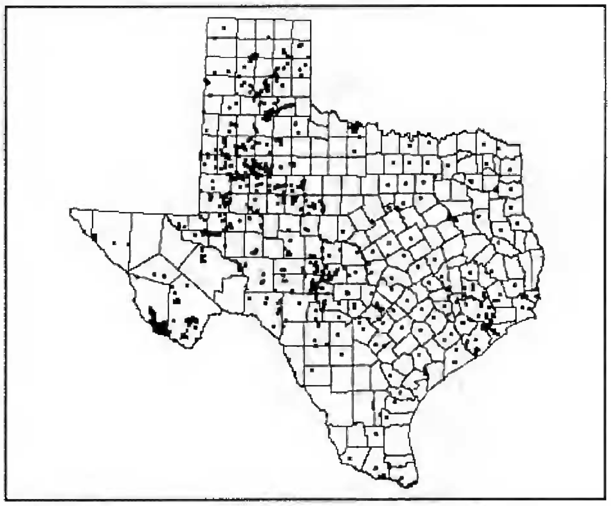


Figure 15. Localities of mammal specimens housed at the Natural Science Research Laboratory that were collected after 1 January 1990 and before 1 January 1999.

gists who were active at Texas Tech during this time include: J Knox Jones, Jr., Clyde Jones, Robert D. Bradley, Hugh H. Genoways, Dilford C. Carter, Michael R. Willig, Ronald K. Chesser, Robert D. Owen, Stephen L. Williams, and others.

Figure 16 shows application of the precision index value. Only those locations with a precision index value of 1.1 have been mapped. These locations are recent as Global Position System receivers have become readily available in the 1990's.

Mammalian distributions may also be mapped using the locality data from museum collections as is shown by the example of *Peromyscus boylii* shown in figure 17. This is a method whereby published range extent may be compared to predicted range and actual collection localities (Allen, 2000).

Records to which UTM coordinates have been assigned become much more valuable because they can be used to answer many varied queries as shown by the maps above and may also be analyzed in combination with data sets found in other relational databases.

By developing information systems, humankind has an increased ability to comprehend data that surrounds us. Regardless of the discipline, decisions based on a huge amount of data cannot be made efficiently without information systems. Biological Informatics provides a new way of decision making in biology. It includes not only the process of data analysis, but also "the delivery of the data and its synthesis to potential users" (Parker et al., 1998). Museum data that are compatible with computer analysis become a source of information for many aspects of biological science and other related subjects and are more readily analyzed by GIS for "delivery" to users.

Biological Informatics is the key to producing analyses and syntheses of data and provide results using specific biological methods. For instance, scientists can visualize the distribution of specimens by genus or species all around the world in conjunction with diseases that occurred twenty years ago. Decisions that are based on the field of Biological Informatics will be impacted and limited by information processing techniques, software development and availability, and accuracy, precision, and reliability of information. However, the benefits to society can be invaluable (Baker et al., 1998).

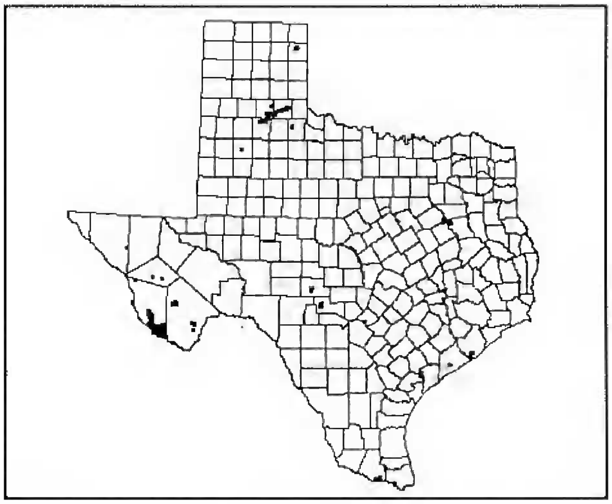


Figure 16. Localities of mammal specimens housed at the Natural Science Research Laboratory that have primary data (precision index 1.1).

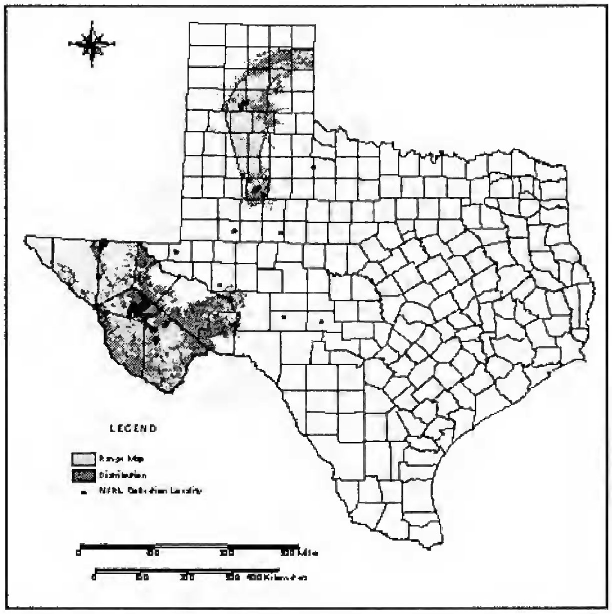


Figure 17. An example of Kelly Allen's dissertation work (Texas Tech University) showing distribution of the brush mouse (*Peromyscus boylii*). Light gray areas represent the range extent as published in Davis and Schmidly (1994) while the dark gray areas represent predicted habitat modeled using GIS. Collection localities indicate voucher specimens labeled as *Peromyscus boylii* and housed in the Natural Science Research Laboratory.

CONCLUSION

UTM Converter was designed to assign GIS coordinates for analysis in a relational database environment. It has the ability to analyze the traditional reference point locality data and to automatically assign UTM coordinates. It also records a precision index value for each locality to which coordinates were assigned.

Records to which UTM coordinates have been assigned are much more valuable than records without GIS-compatible coordinates. Examples have shown that several different types of questions may be answered by the database that were not readily possible before UTM coordinates were assigned to the locality data. Database users can obtain data searched by any of several fields including genus, species, county, collector, date, etc.

It is theoretically possible that application of Artificial Intelligence technology to this topic will allow further developments such as the inclusion of different types of localities for analysis and the ability of *UTM Converter* to teach itself to assign UTM coordinates to records that do not conform to standards such as those that had to be processed manually in this project.

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APPENDIX

Coordinate Precision Index Values
Reprinted by permission of American Society of Mammalogists
(Documentation Standards for Automatic Data Processing in
Mammalogy, Version 2.0, McLaren et al., 1996, page iv-15)

Coordinate precision index values are used to indicate the reliability of the coordinates that have been applied to a given collecting locality.

1.1 Designates coordinate data as entered by the collector and accurate to ±10 meters; e.g., data obtained using GPS technology.

1.2 Designates coordinate data as entered by the collector and accurate to ±100 meters; e.g., data extrapolated using 1:24,000 topographic map.

1.3 Designates coordinate data as entered by the collector and accurate to ±1 kilometer; e.g., data extrapolated using 1:100,000 scale map.

2.0 Designates coordinate data which has been looked up in tables listing coordinates for various place names on the globe. Precision: Collection site within 3 miles of coordinates given.

3.0 Designates coordinate data which have been computerized from relative distance data. It would also include center coordinates for small islands and other small geographic features.

4.0 Designates center coordinates for larger geographic features given in the collector's data where no precise information is given. This would cover most US counties and larger islands. Precision: Collection site within 30 miles of coordinates given.

5.0 Designates center coordinates for even larger geographic features such as larger US counties, small states and countries, and very large islands. Precision: Collection site within 100 miles of coordinates given.

6.0 Designates larger US counties, small states and countries, and very large islands. Precision: Collection site within 300 miles of coordinates given.

7.0 Designates center coordinates for very large geographic features such as "AFRICA" or "AUSTRALIA." Precision: Collection site 300 miles from coordinates given. Although of marginal value, this value indicates that some LOCALITY information is known.

8.X Designates an interim value, based on one of the above values of precision but where the data have the potential of more precision. This marks them for future reference when the coordinates for this place name may be found. The "X" represents the current precision level used.

9.0 Designates that no LOCALITY data are available. This flags any data in the coordinate field as garbage.